

[54] APPARATUS FOR INCREASING THE
ACCURACY OF ELECTROCHEMICAL
GRINDING PROCESSES

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Related U.S. Application Data

[62] Division of Ser. No. 14,841, Feb. 16, 1970, Pat. No. 3,816,291, which is a division of Ser. No. 830,263, June 4, 1969, Pat. No. 3,533,925, which is a division of Ser. No. 599,051, Dec. 5, 1966, Pat. No. 3,476,662.

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Sept. 24, 1966	Japan.....	41-63165

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[51] Int. Cl. B23p 1/02, B23p 1/12

[58] Field of Search 204/129.46, 224 M, 225

[56]

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UNITED STATES PATENTS

2,899,781	8/1959	Williams	204/129.46
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[57]

ABSTRACT

Improved electrochemical-grinding apparatus and method whereby the accuracy of reproduction of the electrode contour in the workpiece is sharply increased by limiting the thickness of the electrolyte film carried by the grinding wheel to a minimum. The film thickness is reduced by a scraper or wiper held against the wheel, by directing a stream of high-velocity air thereagainst to dissolve the excess electrolyte, and/or by electrochemically reforming the electrolyte. The wiper may serve as an electrode for the re-formation of the electrolyte film or as the nozzle for the jet of air and is contoured complementarily to the wheel by electrochemical action or casting there-against. Both the wheel and the electrode are preferably composed of graphitic materials.

6 Claims, 14 Drawing Figures

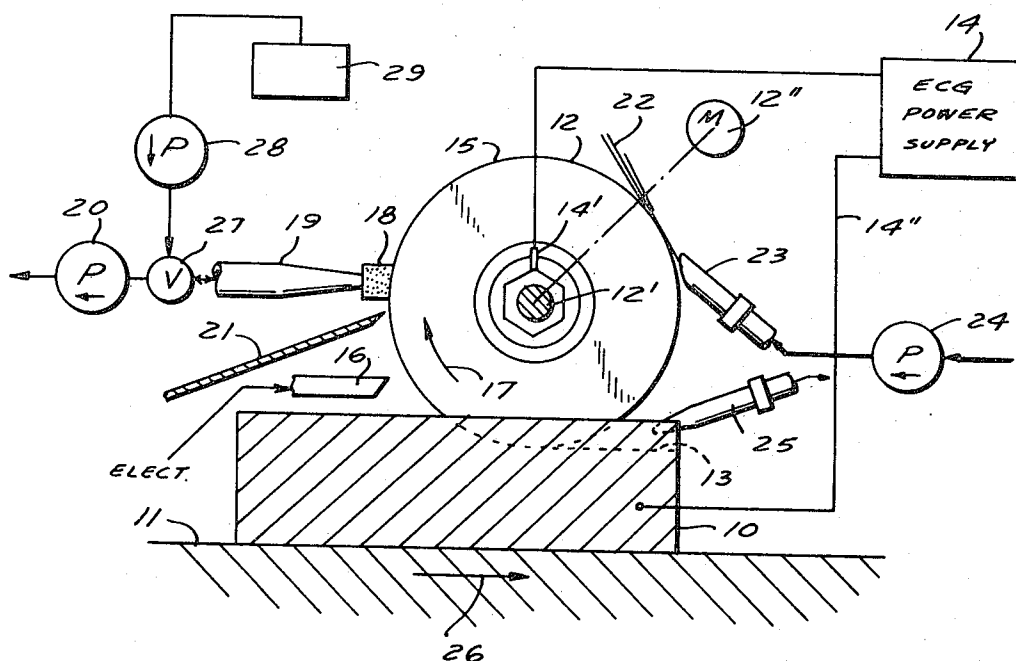


FIG. 1

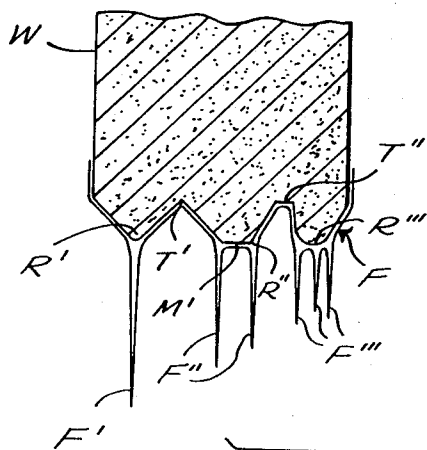


FIG. 2

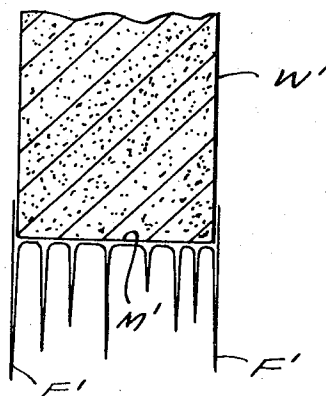
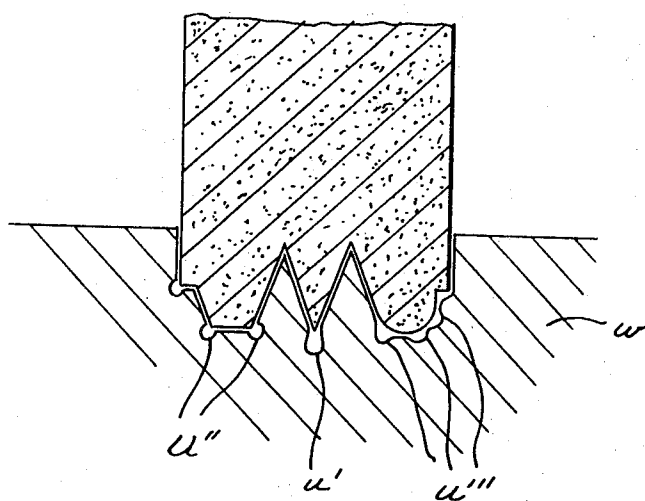
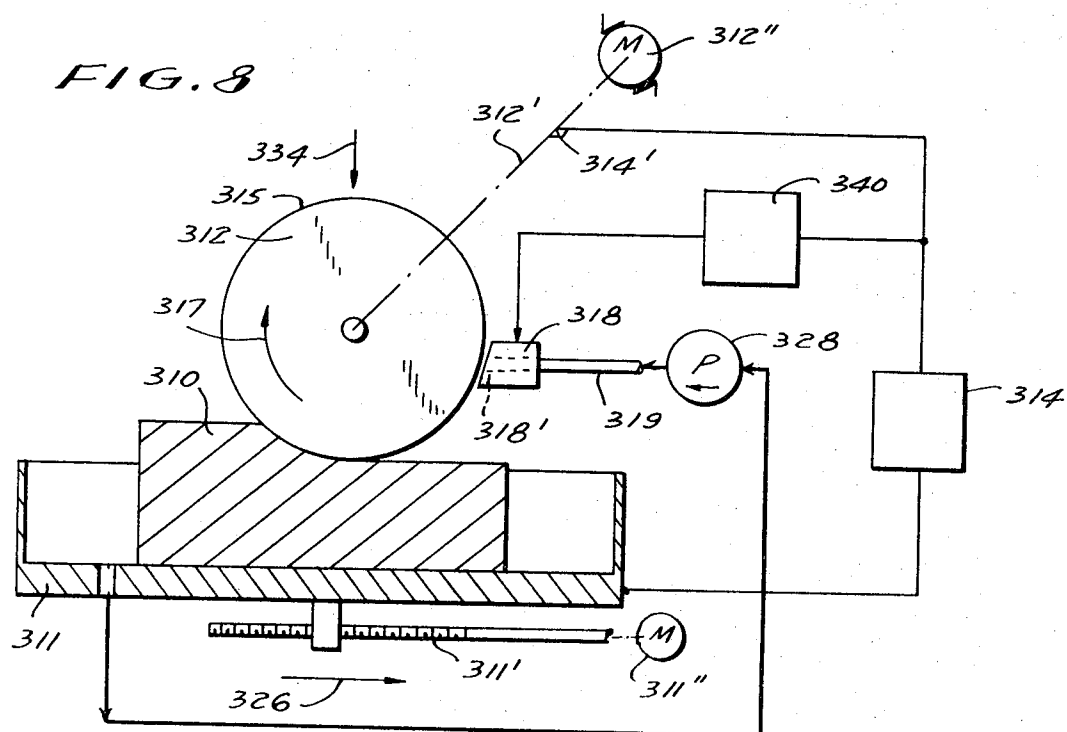
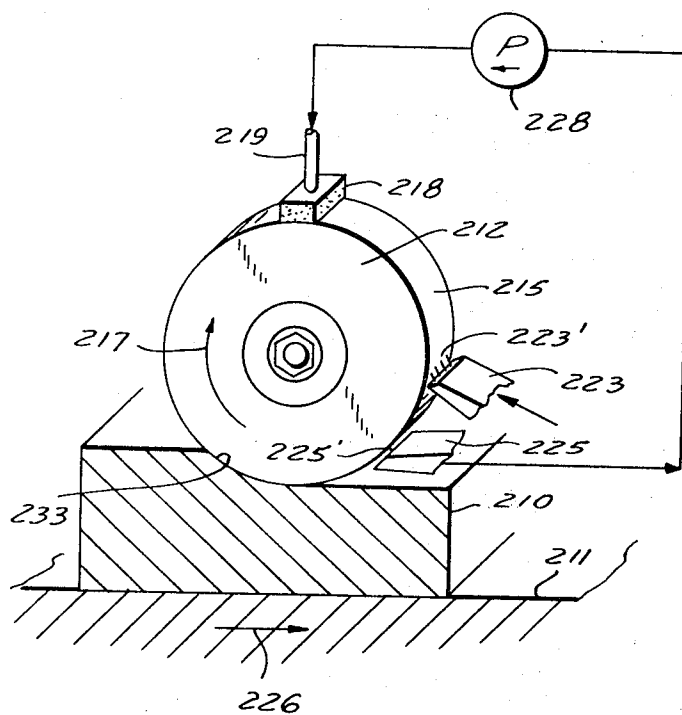


FIG. 3





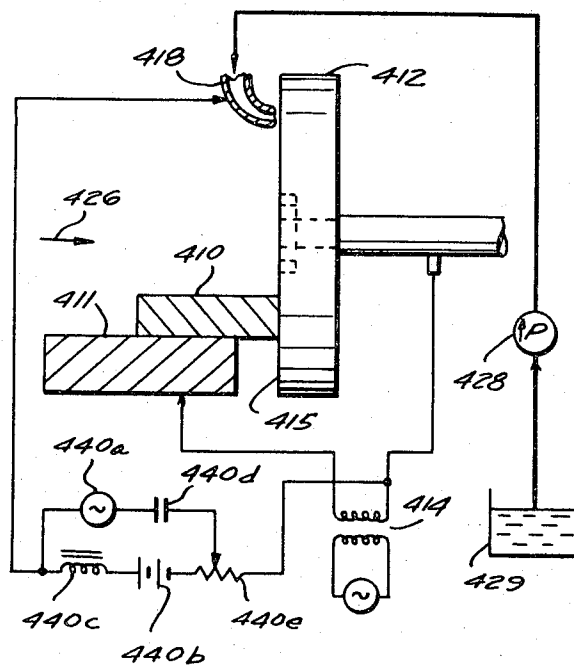
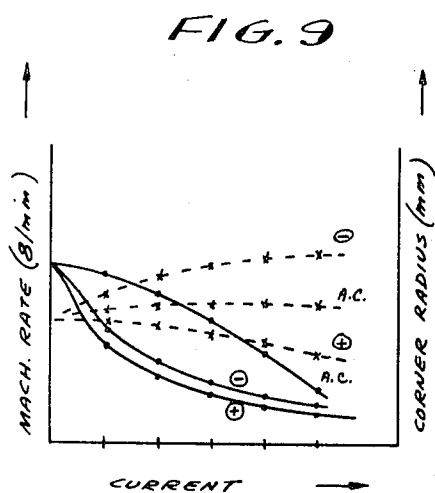


FIG. 10

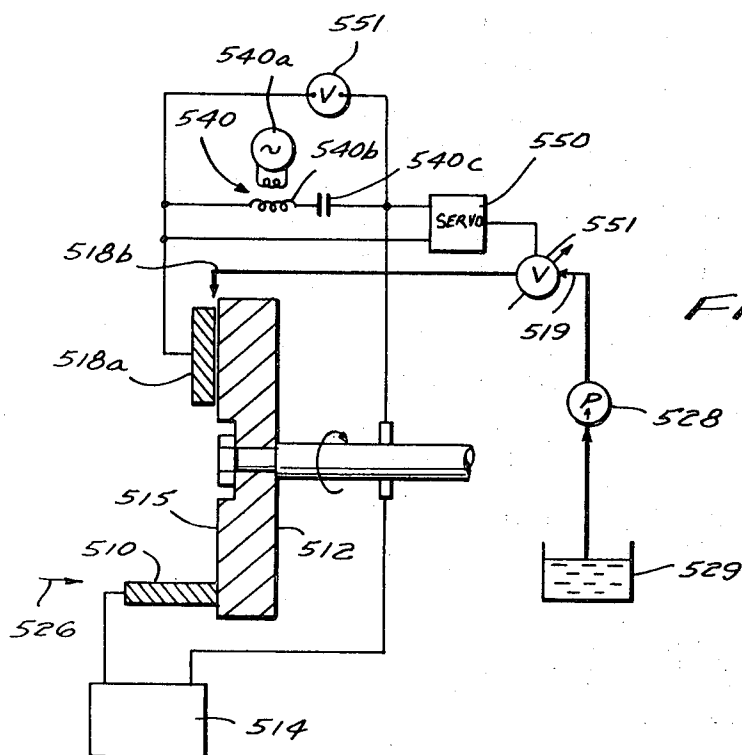
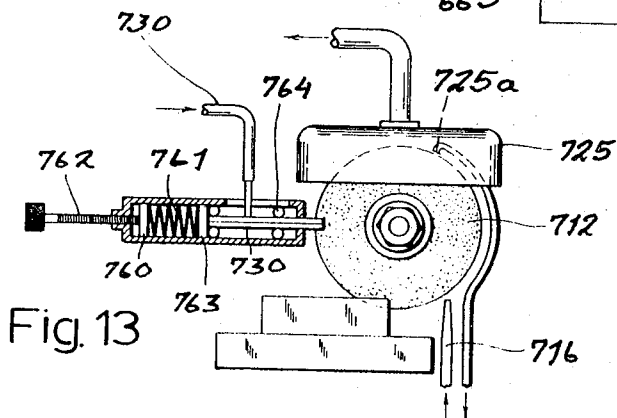
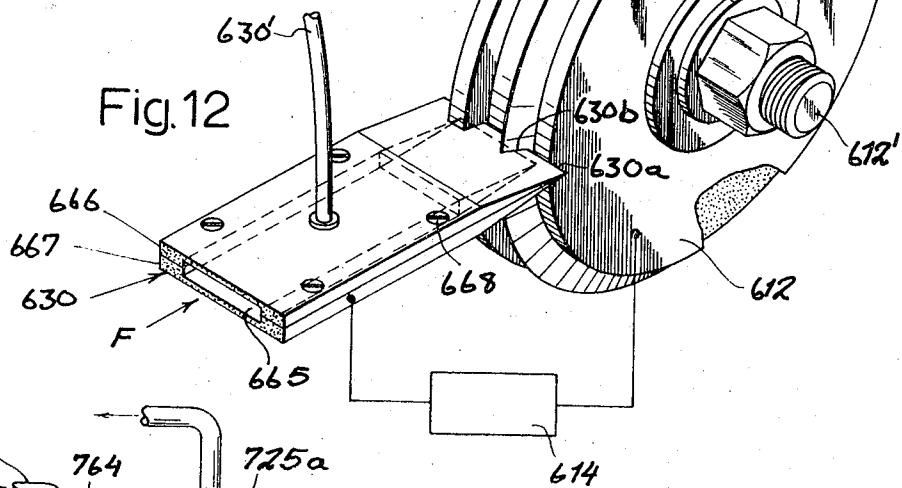
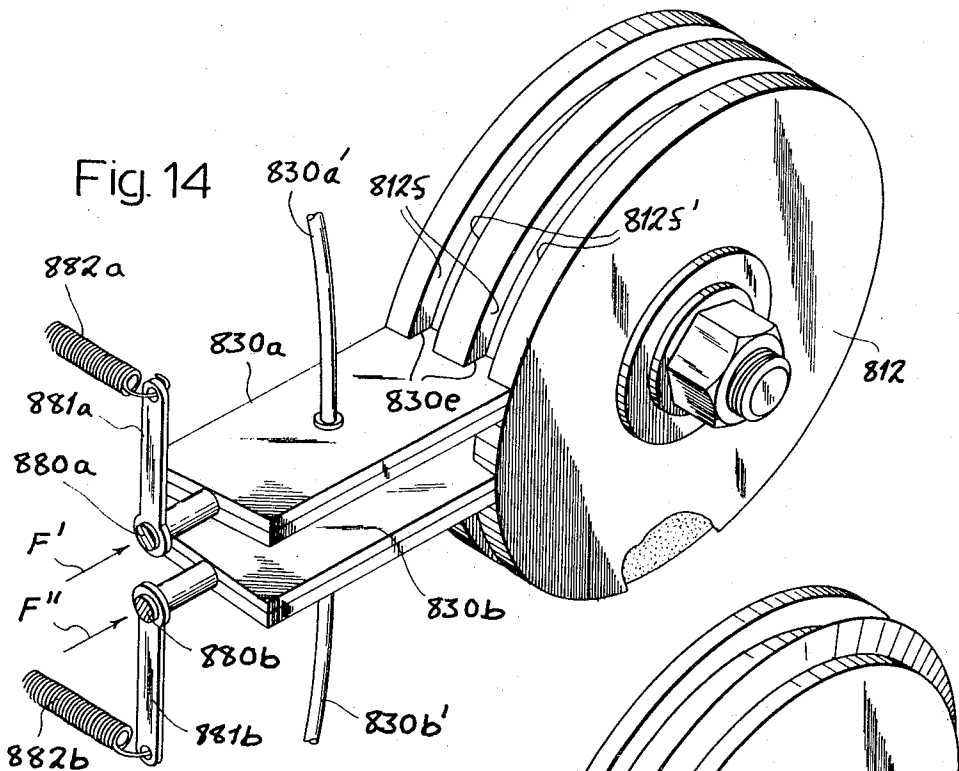


FIG. 11



OSCILLATING BARRELS INCLUDING ELECTRICAL CONTACT MEANS

This application is a continuation-in-part of copending application, Ser. No. 145,254, filed May 20, 1971, and now U.S. Pat. No. 3,723,284 granted Mar. 27, 1973.

The aforementioned abstract is neither intended to define the invention of the application which, of course, is measured by the claims, nor is it intended to be limiting as to the scope of the invention in any way.

The invention relates to a galvanizing device having a drum adapted to receive the articles to be galvanically treated.

U.S. Pat. No. 3,058,902 discloses a rotary drum which has contact rods in the drum space which are secured to an end face of the drum and to a metallic contact disc incorporated in the end face of the drum. The contact disc is slipped over a bearing sleeve which is mounted so as to be rotatable on a bearing pin that is electrically connected to the current supply in order to provide a central current supply through the bearing of the drum. This method of current collecting is a disadvantage because of the line contact existing during drum rotation; that is, bearing play occurs between the bearing axle and the bearing sleeve and produces a relatively bad current collection which requires a longer treatment period for the components and hence an increase in costs for the galvanizing. Moreover, the shape of the drum and the rotary motion of the drum frequently results in inadequate turning over of the articles to be galvanized, especially since the articles are moved in one direction. The contact disc moreover cannot be replaced when required without detaching the end face parts of the drum.

U.S. Pat. Nos. 2,830,946 and 2,479,323 disclose oscillating drums in which current is supplied to the articles being galvanized by means of cables projecting into or suspended in the interior of the drum having contact members at the end faces. The ends of the contact cables, remote from the interior of the drum, are located on contact discs provided with a central current supply passing through the bearing between the bearing axle and the bearing bore. Herein too there is an inferior current supply to the articles being galvanized and hence a longer galvanizing period required, which is uneconomical. In these patents the oscillating drum is provided with a base of W-shaped transverse cross-section. However, because of the straight surfaces of both channels of this W-shaped base the drum does not provide sufficient movement (revolution and intermixture) of the articles being galvanized.

The object of the invention is an improved galvanizing device with which satisfactory galvanizing may be obtained in a relatively short time. The drum, comprising this invention, is of simple structure, stable, has a long life, and is provided with a reliable current supply, permitting proper current collection. Moreover, the drum comprising this invention is formed as an oscillating drum and has a cross-section which ensures an improved intermixture of the articles to be galvanized.

The galvanizing drum in accordance with the invention is distinguished by a simple, stable structure and an optimum current collection from the current supply. Due to a high current supply, the structure of the present invention permits shorter galvanizing times than galvanizing drums hitherto available, thus ensuring an economical operation.

The current supply is preferably not coupled to the drum mounting, but occurs at two contact members so as to be readily interchangeable at each end face of the drum. The contact rods leading into the drum interior are located so as to be readily interchanged. The contact members may be interchanged and/or replaced without dismounting them from the drum.

Moreover, the preferred heart shape or inverted heart shape of the drum cross-section ensures a better intermixing of the articles being galvanized, since in each of the two trough-like channels or grooves of the drum base a favorable rolling motion and intermixing of the individual parts occurs during the oscillation of the drum. The two base hollows ensure a substantially better intermixing of the parts to be galvanized than heretofore with known V-channels of a W-shaped oscillating drum base.

BRIEF DESCRIPTION OF THE DRAWING

In the various figures of the drawing, like reference characters designate like parts.

In the drawing:

FIG. 1 is a perspective view of an electroplating device comprising this invention;

FIG. 2 is a transverse cross-section view through the pendulum drum shown in FIG. 1;

FIG. 3 is a longitudinal sectional view through the pendulum drum shown in FIG. 1;

FIG. 4 is a fragmentary sectional view taken at point "A" in FIG. 3;

FIG. 5 is a fragmentary sectional view taken at point "B" in FIG. 3;

FIG. 6 is a fragmentary view, partially in section, taken at point "C" in FIG. 3;

FIG. 7 is an end elevational view of a pendulum drum in accordance with this invention; and

FIG. 8 is an end elevational view of the index ring of FIG. 7 in an inverse pivotal position.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A plating device of the invention for the galvanic surface treatment of merchandise (shaped parts) possesses a pendulum drum 12, which is mounted so as to be pivotable to and fro in a carrying frame 10, and defines openings 11 on the side of the casing for the passage of a medium, the drum being rotatably and detachably supported in the carrying frame 10 by means of two facing bearings 13 which form a pivotal axis.

The pendulum drum 12 shows in cross-section several wall parts 15 and 16, connected together to form an incomplete heart shape, with a filling and emptying aperture 14, the wall parts 15 have cross-sections which are annular, and the wall parts 16, in cross-section, are part curved, part straight.

Adjacent wall parts 15 and 15, as well as 15 and 16 are connected together by a common strengthening bar 19 which simultaneously forms a support 17 for a contact bar 18, which is partly enclosed therein, and is connected to a current supply. The individual wall parts 15 and 16 of the drum 12 are fastened by welding to the strengthening bars and by welding to end plates 20, which terminate the drum 12 at each end.

To facilitate a welded connection between wall parts 15 and 16, and strengthening bars 19, the edge regions of the wall parts 15 and 16 fit in channels 21 of the

strengthening bars 19, which are preferably formed as extrusion profiles.

Each strengthening bar 19, which has a circular, angular, or oval cross-section, defines a recess 17 over the entire length of the bar, which is the same shape as the cross-section of the contact bar 18. There is a channel 21 on both sides of this recess to receive walls parts 15 and 16, which are welded with the strengthening bars 19 to the inside and outside of the drum, in the region of these channels 21.

Each contact bar is formed from two cathode rods which are arranged coaxially, and are electrically connected, each rod having a circular cross-section.

To agree with the cross-section shape of the cathode rods, each strengthening rod 19 has a partially circular recess in which the two coaxially running cathode rods 18 are mounted, and from which part of their surface projects is exposed to make contact with the shaped parts to be galvanized.

The heart shape of the pendulum drum 12 is formed by the four wall parts 15 and 16, which are connected together by three strengthening bars 19. The two adjacent partially circular (annular) shaped wall parts 15 represent the floor region of the drum 12, and to each wall part 15 the curved part of a wall part 16 is connected the rectilinear regions of the wall parts forming the opening 14 at the top.

The ends of the strengthening bars 19 fit into recesses 22, which extend part way through the ends 20.

The wall parts 15 and 16 are braced on the inside of the drum by ribs 23, and in the region of the filling and emptying opening 14, by exterior bars 24.

The wall parts 15 and 16, the strengthening bars 19, the end walls 20 and the stiffening ribs 23, as well as stiffening bars 24 of the pendulum drum 12, are of plastics material such as polypropylene, and the wall parts 15 and 16 preshaped while hot.

The wall parts 15 and 16 extend in over the entire length of the drum; they can, however, be formed from several parts, extending over the longitudinal direction of the drum.

Each contact bar, which runs the entire length of the drum, and is formed from two coaxially arranged cathode rods 18, mounted in a common recess 17 of the strengthening bar 19, is held detachably in the drum 12, in the central longitudinal region or elsewhere, by a bridge 25 of non-conducting material; this bridge 25 consisting of plastics material, covers a joint between the two coaxial cathode rods 18, the joints including a spigot 18a of the adjacent contact bar. The bridge is fixed detachably according to position, by a bolt 26 which passes through the strengthening bar 19, and is secured by a nut screwed onto the outside of the drum, in the connection region of two cathode rods 18.

Each cathode rod 18, at its end away from the plastics bridge 25, passes sealingly through the end wall 20 of the drum, and is connected to a contact part 32 which is covered by an insulation layer 28 which is insulated from the end wall 20 of the drum and fastened detachably to the outside of it; there is a terminal 30 for an electric current supply line 31.

The contact part 32 is formed from a metal plate 29, with the metal terminal 30 fastened on it, and an insulation layer 28, preferably of rubber, which surrounds this metal core 29 and the terminal 30 on all sides up to the points of contact with the cathode rods 18 and the current cable 31 (compare FIGS. 4 and 5).

The cathode rod 18 is fastened to the contact part 32 by a threaded end 33, and is detachably connected to the contact part 32 by a nut 35 which is screwed on to the outside of the end 33. The nut is covered by an insulation cap 34; the contact connection between cathode rod 18 and contact part 32 takes place inside the bore of the metal core 29, which accepts the threaded end 33.

The contact part 32 provided on the outside of each end wall 20 of the drum extends part-circularly around the bearing axis 13 of the drum, and is detachably fastened by means of several screws 36 which penetrate through bore-holes covered by the insulation layer 28, and by nuts 37, to the end wall 20 of the drum.

The terminal 30 extends from an end region of the partially circular contact part 32, and has a hole 38 to receive a contact end 39 of the conductor 31, which is insulated against moisture. The contact end 39 is connected detachably to the terminal 30 by a nut 41 which is screwed onto the end 39 and which is covered by an insulation cap 40. All cathode rods 18 are supplied with current by this terminal 30, one of which is provided on each contact part 32.

The carrying frame 10 is formed from two carrying plates 43 which are connected together by tie rods 42, and accept the stub shafts 13 of the drum. On this carrying frame 10 is mounted a propulsion device 44, a driving motor with gearing, which is connected, by its driving pinion 45 via an intermediate wheel 46 to a toothed wheel 47 which is fastened to one end of the drum. The motor drives the pendulum drum 12 with a rocking (to and fro) movement.

The carrying frame 10 has two carrying plates 43 with two pins 48 with which the carrying frame 10 and its pendulum drum 12 can be suspended as a unit in the forks 49 of a treatment bath container 50, a filling or emptying container, a drying kiln, a transport device 51 or the like.

Each carrying frame plate 43 has a conductor rail 52 to which the current conductor 31, which leads to the contact part 32, is connected. The current supply for the pendulum drum 12 is derived from a low voltage source with a high current output (e.g. 750 amp. at 15v). The current is brought to the conductor rail 52, in each case via a current supply line 63 which is connected to the forks 49, and the pins 48 enclosed therein, from which the current reaches the cathode rods 18 via the line 31 connected to it (and via the insulated contact part 32).

The current supply for the propulsion motor 44 is separately derived from a connector 53 which is located at one end of the frame 10. This connector 53, upon insertion of the drum 12 in the bath container 50, is connected to a complementary part 54 which is arranged on the container 50; three-phase current is used for the propulsion motor 44, the current being fed through a line 64 of the counter-contact device 54.

On the front of the drum facing the gear motor 44, there is a plastic index ring 55 surrounding the stub shaft 13, to which several metallic switching plates 56, 57 and 58 are fastened, which cooperate with a commutator 59 fastened detachably on the container 50 for control of the drum 12 between its two end positions, and the filling or emptying position. The commutator has an index ring 55 on which there are two metal plates 56, two metal plates 57 and one metal plate 58, which are spaced from one another, and at three differ-

FIG. 14 is a perspective cross-sectional view of another grinding system illustrating the principles of the present invention.

SPECIFIC DESCRIPTION

In FIGS. 1 and 2, I show diagrammatically the nature of an electrolyte film F along the machining face M of a graphite wheel W used for the electrochemical grinding of a workpiece (not shown) in accordance with any of the systems set forth in my copending applications mentioned above. The profiled wall W is formed with a series of ridges R', R'' and R''' along the machining face with intermediate troughs T' and T''. Ridge R' is of wedge-shaped section and tends to cast off the electrolyte film F in a relatively extended sheet F' whereas the ridge R'' is flattened so that somewhat shorter sheets of electrolyte F'' are cast off in the radial direction. A rounded surface such as that of the ridge R''' forms still smaller disk-like streams F''' of electrolyte. When the machining face M closely approaches a workpiece as illustrated at w, for example, in FIG. 3, these spurious streams of electrolyte F' to F''' appear to give rise to undercutting of the channels machined into the workpiece w at U', U'', U'''. Thus the profile of the machine surface differs materially from the profile of the contoured electrode.

As illustrated in FIG. 2, the disadvantages described above also characterize smooth surface wheels such as that at U'. Here the machining face M' is cylindrical although the electrolyte film is again nonuniform and is cast off in radial sheets F' etc. When this wheel is used to machine a workpiece with any of the systems illustrated in the aforementioned copending applications or even with conventional electrochemical grinding apparatus, surface irregularities are found in the workpiece in spite of the relative smoothness of the tool electrode. In fact, I have discovered that the roughness and inaccuracy in the surface of the workpiece derives in large measure from the nature and character of the electrolyte film.

The disadvantages discussed in connection with FIGS. 1 - 3 can be avoided, in accordance with one aspect of the present invention, by removing excess electrolyte from the machining face of the tool electrode and/or by applying the electrolyte thereto in such manner that a thin film of electrolyte or a monolayer only is formed uniformly along the electrode surface.

In the system of FIG. 4, a workpiece 10 is shown to be supported on a crossfeed carriage 11 of conventional construction and to be juxtaposed with an electrochemical grinder wheel 12 (e.g. of graphite). The wheel 12 is used to form a channel 13 in the workpiece and for this purpose is connected to an electrochemical grinding power supply 14 adapted to apply direct or alternating current across the wheel 12 and the workpiece 10 against which the wheel is urged.

The wheel is preferably constructed in the manner set forth in my copending application Ser. No. 565,670 of June 30, 1966 while the electrolyte recirculation apparatus, the power supply and the feed systems can be any of those described and illustrated in my applications Ser. No. 512,338 of Dec. 8, 1965 and Ser. No. 562,857 of July 5, 1966.

A power supply of this type is represented at 14 in FIG. 4 and has one terminal connected to a wiper 14' which, in turn, engages the shaft 12' of the grinding

wheel 12. The other terminal 14'' is connected with the workpiece 10.

The grinding wheel 12 has its shaft 12' driven by a motor 12'' and is formed with a cylindrical machining face 15 to which the electrolyte is supplied via a nozzle 16 close to the point at which the machining surface 15 rises from the workpiece 10. The electrolyte-coated machining surface is carried in the direction of arrow 17 (i.e. clockwise) past a wiper 18 of a porous material to which a suction pipe 19 is connected.

A negative-pressure blower or suction pump 20 communicates with the line 19 so that the head 18 simultaneously wipes the electrode surface 15 and sucks excess electrolyte therefrom through the porous body 18. An apron or guide 21 below the wiper 18 conducts the squeezed liquid away from the machining face. After the endless and continuous machining face 15 sweeps past the sponge-like suction wiper 18, a relatively thin film of electrolyte remains upon the surface.

This thin film may be further reduced by a jet of high-pressure air represented at 22 and directed from a nozzle 23 generally tangentially against the machining face 15 counter to its direction of rotation. I have found that such a jet does not decrease the uniformity of the film in the sense that one might expect but rather markedly improves the machining accuracy. In fact, the jet 22 may be used alone in the event the head 18 is omitted. A blower 24 delivers compressed air to the nozzle 23.

A further suction nozzle 25 is open toward the machining zone to collect any electrolyte which might otherwise tend to accumulate there, thus insuring that only the thin film will be entrained by the tool electrode 15 through the machining zone. The workpiece 10 is displaced in the usual manner on its cross slide or the like in the direction of arrow 26 to produce the channel 13. The duct 19 can be provided with a three-way valve 27 to which an electrolyte-circulating pump 28 and a reservoir 29 of electrolyte are connected when it is desired to feed the electrolyte into the system through the porous applicator 18. In this case, only the blower 23 functions as a means for removing the excess electrolyte.

In FIGS. 5 and 6, I show another system for removing electrolyte from the surface 115 of a contoured graphite electrochemical grinding wheel 112. A nozzle 116 here delivers the electrolyte to the machining face 115 and the excess is removed by a thin synthetic resin foil 130 whose edge 131 is complementarily contoured to interfit with the ridges 115r', 115r'' and 115r''' of the wheel 112. The foil 130 is turned against the wheel 112 so as to form a scoop along which the excess electrolyte flows away from the machining face 115 prior to its engagement with the workpiece 100 to form a complementary profile 113 therein. Only a monolayer or thin film of electrolyte remains on the lower right-hand quadrant of the contoured wheel 112 as the machining surface is brought into contact with the workpiece or juxtaposed therewith adjacent this quadrant.

The foil 130 can conduct electrolyte to a reservoir 129 from which it is supplied, via the usual filters and the like, to the nozzle 116 via a pump 128. In practice, it has been found that the major part of the electrolyte applied to the surface 115 of the wheel 112 is recovered at 129 so that only a thin film remains upon the machining surface as indicated. Replenishment of the electrolyte is carried out via a supply reservoir 132 whose valve 133 feeds additional electrolyte into the

circulating system in proportion to the volume of the electrolyte film withdrawn from this system. Of course, it is also possible to provide a collecting vessel for recoverable electrolyte which may run off the workpiece and, in this case, this fraction of the electrolyte is filtered and returned to the circulating path as well.

It has occasionally been found to be economical to discharge this portion of the electrolyte, however, which sustains the greatest contamination. The thin film at the machining face resulting from the wiper action of the foil 130 completely eliminates undercutting as discussed in connection with FIGS. 1-3, presumably because the electrolyte flow pattern F' , F'' etc. no longer results and the electrolyte clings closely to the electrode surface.

In another modification of the present system as illustrated in FIG. 7, the workpiece 210 is fed in the direction of arrow 226 on the usual cross slide or carriage 211 while the electrochemical grinder wheel 212 is coated with electrolyte from a porous block 218. Excess electrolyte is removed from the machining surface 215 of the wheel by directing a sheet-like jet of air thereagainst counter to the direction of rotation of the wheel (arrow 217) from a nozzle 223 whose mouth 223' is the entire width of the machining face 215. Here the nozzle 223, which is connected to the blower or compressor as described in connection with FIG. 4, is located substantially at the lower right-hand quadrant and not more than 90° ahead of the workpiece or machining zone in the angular sweep of the surface 215.

Also in this zone, I provide a suction head 225 whose suction aperture 225' is closely spaced from the surface 215 while spanning the entire width of the latter. A pump 228 circulates electrolyte connected at the suction nozzle 225 and connected from the workpiece 210 to the pipe 219 supplying the electrolyte-dispensing wiper. In this case, too, the presence of only a thin film of electrolyte at the working zone 233 appears to ensure greatly improved accuracy and freedom from undercutting of the type described earlier.

According to another aspect of this invention; the electrolyte is electrolytically transformed on the workpiece surface with the aid of an auxiliary electrode just in advance of contact between the transformed film and the workpiece such that the recombination time of the transformation is substantially less than the time required to sweep the transformed portion of the electrolyte to the machining interface. For example, it may be assumed that the electrolyte consisting of a sodium-chloride solution is electrically altered to promote the formation of NaOH , ClOH , HOI , NaO^- or other species known to be generated in the electrolysis of sodium chloride, sodium nitrite, potassium nitrite and kindred alkali-metal salts. These species have various recombination times or decomposition periods leading toward restoration of the simple K^+ , Na^+ , Cl^- , NO_2^- , NO_3^- and hydrated-ion condition of the electrolyte. It appears that the aforescribed electrically transformed electrolyte is capable of eliminating inaccuracies resulting from undercutting of grooves and overcutting (in the sense of excess material removal). Greater reproduction accuracy of the contours of the electrochemical grinding wheel is obtained. It may be noted parenthetically that at least part of the effect of electrical transformation of the electrolyte layer on the tool electrode may derive from ohmic heating of the electrolyte and

vaporization thereof to leave a reduced film thickness thereon.

In FIG. 8, I show an electrochemical grinder having an electrolyte collection trough forming a receptacle 311 in which the metallic workpiece 310 is disposed. The trough 311 can be shifted in the direction of arrow 326 via a diagrammatically illustrated lead screw 311' and feed motor 311''. The graphite electrochemical grinding wheel 312 is supported in a conventional head and urged against the workpiece 310 under spring or fluid pressure in the direction of arrow 334 (as described and illustrated in the aforementioned copending applications dealing with electrochemical grinding). The shaft 312' of the wheel 312 is driven by the motor 312'' in the direction of arrow 317 so that the machining surface 315 sweeps past a discharge nozzle 318 delivering electrolyte to the face 315. A recirculation system represented by the pump 328 and the pipe 319 delivers electrolyte to the nozzle 318. The power supply 314 is connected across the workpiece 310 and the wheel 312 is of the type disclosed in the above-mentioned copending applications and can be direct current, direct current superimposed upon alternating current or even alternating current. According to the present improvement, the nozzle 318 forms an auxiliary electrode whose face 318' is closely juxtaposed with the machining face 315 of the tool electrode so that the electrolyte film between them forms a bridge and is electrically transformed directly upon the machining face. For this purpose, a further power supply 340 is connected between the wheel 312 (via its shaft 312' and a brush 314') and the auxiliary electrode 318. As will be apparent hereinafter, the power supply 340 may be a direct-current source so poled that the auxiliary electrode 318 is relatively positive or relatively negative or an alternating current source. The passage through the auxiliary electrode 318 thus delivers the electrolyte to the machining face.

In FIG. 9, I show a graph of the machining characteristics as a function of the current applied between the workpiece electrode 312 and the auxiliary electrode 318. In FIG. 9, the electrolyte transformation current is plotted along the abscissa while the machining rate (broken-line curves) in grams per minute and the corner radius (solid-line curves) in mm are plotted along the ordinate. A series of three graphs are provided in each set for the auxiliary electrode relatively negative and relatively positive (d.c. supply) and for an alternating-current auxiliary supply. The corner radius obtainable with the auxiliary electrical modification of the electrolyte (with a.c. or d.c.) is a marked improvement over any obtainable without such modification although a relatively positive auxiliary electrode provides the greatest reduction in corner radius with increase of current flow. In all cases, the accuracy increases sharply initially and tends to level out with increasing auxiliary current and at the upper current-amplitude ranges, no substantial further loss in machining speed is observed; the machining rate generally increases although a decrease is observed when the auxiliary electrode is relatively positive.

In FIG. 10, I show a modified electrochemical current system wherein a workpiece 410 such as a tool bit or the like is ground between the annular face 415 of a graphite electrochemical grinding tool of the type described and illustrated in my application Ser. No. 565,670 filed June 30, 1966. The workpiece 410 is

mounted on the carriage 411 and is urged in the direction of the wheel 412 (arrow 426) via fluid- or spring-pressure means and the usual leadscrew.

The electrochemical-grinding power supply 414 is represented as a transformer connected to an a.c. line and functions as set forth in the copending applications mentioned above. Here, however, the electrolyte is delivered from a reservoir 429 via a pump 428 to the nozzle 418 which also serves as an auxiliary electrode to electrically transform the electrolyte film. For this purpose, the auxiliary power supply connected between the electrode 418 and the grinding wheel 412 comprises an alternating current source 440a capacitively bridged across a direct-current source 440b whose inductance 440c limits current surges.

The capacitor 440d is connected in series with the alternating-current source and the slider or wiper of a potentiometer 440e in series with the auxiliary electrode 418 and the tool electrode 412. The potentiometer 440e thus can be adjusted to control the amplitude of the alternating current superimposed upon the d.c. electrolyte-transforming current passing through the electrolyte film bridging the auxiliary electrode 418 and the tool electrode 412. Again, a substantial improvement in machining accuracy is obtained.

In the modified system of FIG. 11, the auxiliary electrode 518a is constituted by a graphite wiper spanning the radial width of the transverse annular machining surface 515 of the graphite wheel 512. A tool bit or other workpiece 510 to be shaped is urged in the direction of arrow 526 against the face 515 and ECG machining current is applied against the workpiece 510 and the tool electrode 512 via a source 514. The wiper 518a thus serves to mechanically remove excessive electrolyte and as the auxiliary electrode for its electrical transformation. The auxiliary current source 540 connected between the auxiliary electrode 518a and the tool electrode 512 across the electrolyte film, is constituted of an a.c. generator or line 540a connected via an isolation transformer 540b and a d.c.-blocking capacitor 540c between the auxiliary and tool electrodes. A voltmeter 551 is in parallel with the a.c. source 540 to measure the amplitude of the auxiliary voltage.

A servomechanism 550, responsive to voltage fluctuations, is connected across the auxiliary electrode 518a and the tool electrode 512 to regulate the flow of electrolyte to the dispensing nozzle 518b via the electromagnetically controlled valve 519. The circulating pump 528 delivers electrolyte to this valve from the reservoir 529. When the electrolyte film on the surface is of the proper thickness and character, it possesses a predetermined resistance so that a voltage below a predetermined peak is sensed by the servomechanism 550. When, however, the resistance rises between the auxiliary electrode 518a and the tool electrode 512, the servomechanism 550 operates the valve 519 to supply more electrolyte to the face 515 and thus correct the film thickness. When excess electrolyte is present, the reduced resistance is also sensed by the mechanism 550 which reduces the supply of electrolyte to restore the optimum film thickness and character.

In the systems of FIGS. 8-11, I have found it advisable to add long-chain alcohols, organic acids and organic oils to the electrolyte undergoing electrical transformation in the film upon the machining surface; it appears that the electrolytically produced species or frag-

ments (e.g. KOH, NaOH and ClOH) may react chemically with these surfactant-forming organic compounds to stabilize the electrical transformation and produce surface-active agents which also favorably modify the characteristics of the electrolyte in the sense that an improved machining accuracy is obtained. In the system of FIG. 8, for example, the auxiliary electrode 318 must be located at, say, 10° above the machining zone for most machining speeds unless a transformation stabilizer is provided. Of course, the angle can be approximately doubled when the peripheral speed of the wheel is doubled, the consideration being the recombination rate of the electrochemically produced species.

The following Examples illustrate how the present invention can be carried out in practice.

EXAMPLE I

Using the apparatus illustrated in FIGS. 5 and 6, a graphite electrochemical grinding wheel having a diameter of 180 mm and a specific resistivity of 3.4×10^{-3} ohm-cm and a width of 20 mm was used to grind a 0.55% (by weight) carbon steel (S55C) workpiece. The machining face of the wheel had a serrated profile with four teeth with apex angles of 60° each and flank heights of 3.5 mm. The peaks were, therefore, spaced apart from one another by 3.5 mm. The peripheral speed of the machining face of the wheel was 22.5 m/second and the electrolyte constituted of an aqueous solution containing 3% by weight sodium nitrite and 5% by weight potassium nitrate. The pressure applied to the electrode in urging it against the workpiece was 0.1 kg/cm² while the machining power was 7 volta peak-to-peak (50 cycles a.c.) with a mean current of 50 amp.

A foil 130, shaped to be complementary to the configuration of the serrated wheel, was held as illustrated in FIG. 5 with a squeegee gap of 0.02 mm was obtained whereas the corner radius was 0.07 mm when the foil was removed. The machining speed was approximately the same in both cases.

EXAMPLE II

The apparatus illustrated in FIG. 4 was employed to machine a tungsten carbide workpiece containing 5% cobalt. The electrode was simple cylindrical wheel having a serrated periphery as described in Example I and was urged against the workpiece with a pressure of 1.5 kg/cm². The machining current of 80 amp. was delivered at 6 volts peak to peak (50 cycles per second a.c.). The machining depth was 5 mm and the machining speed held at 1.6-1.8 mm/min. When no means was used to treat the film on the electrode surface, the roughness was found to be about 0.5 microns H_{max} and the corner radius 0.3 mm. When, however, compressed air was directed against the tool electrode via the nozzle 23 at a pressure of 6 kg/cm² and a nozzle/electrode gap of 1 mm, machining could be carried out at the same rate with the improved corner radius of 0.08 mm, an accuracy of 0.015 as compared with 0.07 mm of deviation from the contours of the tool electrode.

EXAMPLE III

Using the apparatus of FIG. 8, SK-2 die steel was machined with a graphite wheel having a 1 cm² machining area and a diameter of 150 mm. The speed of the machining surface was 23.2 m/second and 750 cc/min of electrolyte was delivered to the machining zone. The

electrolyte was an aqueous solution containing 2% by weight sodium nitrite and 5% by weight of potassium nitrate; the machining current was 70 amps of direct current. The results obtained with various auxiliary currents without the addition of surfactant formers are graphed in FIG. 9. When the auxiliary current was 100 amps (between the auxiliary electrode 318, disposed 10° above the machining zone, and the tool electrode 312), the machining rate was approximately 0.7 g/min while a corner radius of about 0.006 mm was observed when the electrode 318 was relatively negative. When the auxiliary power supply was alternating current, a machining speed at this auxiliary current flow of 0.5 g/min and a corner radius of about 0.01 mm were noted. When the electrode 7 was relatively positive, an auxiliary current of 100 amps gave about 0.005 mm corner radius and a machining speed of about 0.38 g/min. When the auxiliary current is not applied, the corner radius is invariably greater than 0.03 mm. Thus it can be seen that it is possible to increase the machining rate and accuracy when the auxiliary electrode is relatively negative, to increase the accuracy at the expense of the machining rate when this electrode is relatively positive, and to increase the accuracy without any substantial modification of the machining rate when an alternating current is used as the auxiliary supply.

It is possible to increase the accuracy still further (i.e. to have the corner radius) when a surfactant former is supplied to the electrolyte in the amount of 0.5% by weight, the surfactant former consisting of a long-chain organic compound soluble in the electrolyte at least upon electrical modification thereof. 0.5% solutions of stearic acid, caproic acid, cetyl alcohol, olive oil and asphalt oils in the salt-containing electrolytes described yielded approximately half the corner radius obtained without the surfactant former for the same auxiliary-current flow.

Referring now to FIG. 12, it can be seen that a contoured grinding wheel 612 of graphite, carried by an arbor or shaft 612' and driven by a suitable motor for the grinding of a workpiece in systems similar to those of FIGS. 4 and 6-8, for example, co-operates with a wiper 630 whose front end 630a is tapered forwardly in the direction of the electrode 612 so that an ECG power supply 614 can be connected between the graphite wiper 630 and the wheel 612 to electrochemically machine the scraper 630 to contours 630b complementarily to the contours of the wheel 612 by rotation of the latter and the delivery of the usual machining electrolyte to the region in which the scraper 630 is held against the wheel. A spring force F urges the scraper 630 against the wheel and may be applied to the scraper by the system illustrated in FIG. 13 or any

cess. In practice, therefore, the wheel 612 may be contoured by conventional dressing means initially or by casting in a mold and is thereafter used to contour the scraper 630 by electrochemical machining. Subsequently, the scraper is positioned in place of the scraper 130, for example, and machining of a workpiece carried out in the manner illustrated and described with respect to FIGS. 5 and 6. Since the forward end of the scraper 630 is tapered at 630a and thins down in the direction of the wheel 612, electrochemical machining of the scraper to conform it to the contours of the wheel 612 will be carried out preferentially with a relatively deep cut of the scraper and little, if any, erosion of the wheel.

In an alternative system, the scraper 630 can be formed by casting graphitic material against the wheel whose contours thus determine the complementary contours of the scraper. As indicated above, the scraper 630 is composed of graphite and may, therefore, serve as the auxiliary electrode for electrolytic transformation of the electrolyte. To this end, the power supply 340 may be connected between the electrode 630 and the wheel 612 or the workpiece (not shown) in the manner described in connection with FIG. 8.

EXAMPLE IV

Using a graphite electrochemical grinding electrode as previously described, with a specific resistivity in the radial direction of about $3.4 \times 10^{-3} \Omega\text{-cm}$, a thickness of about 20 mm and a diameter of about 180 mm, electrochemical grinding of a workpiece composed of GE 885 tungsten carbide was carried out. The workpiece had a width of 30 mm and a thickness of 12 mm. The contours of the wheel were formed by four V-shaped grooves with a flank height and separation of 35mm. The electrolyte was an aqueous solution of 5% by weight potassium nitrate and was delivered to the wheel as illustrated in FIG. 5. The grinding wheel was rotated with a peripheral speed of 22.5 m/second and an electrochemical grinding power supply was connected between the wheel and workpiece as illustrated in FIG. 4, to deliver a grinding potential of about 7 volts and a current of 50 amperes at a frequency of 50 cycles/second. The scraper was a graphite plate and a synthetic resin foil (c.f. FIGS. 12 and 6), respectively, in a series of tests. In the following Table, I list the results of five tests, comparing the maximum errors obtained with no scraper, with the improved graphite scraper at scraper pressures (against the wheel) at pressures of 400, 800 and 2200 grams/cm², and a synthetic-resin-foil scraper of the type described in FIG. 6 at a pressure of 800 grams/cm², for machining periods of 22 to 26 minutes and a cutting depth of 5.5 mm.

TABLE

Test No.	Without Scraper	Graphite scraper pressure			Foil scraper pressure 800 g/cm ²
		400 g/cm ²	800 g/cm ²	2,200 g/cm ²	
1	0.062	0.031	0.012	0.013	0.041
2	0.074	0.042	0.011	0.011	0.044
3	0.058	0.028	0.012	0.012	0.051
4	0.06	0.033	0.011	0.012	0.038
5	0.072	0.03	0.012	0.011	0.045

other convenient spring device. In this case, the scraper 630 is, machined as a workpiece to conform to the contours of the wheel 612 prior to the machining pro-

cess. From the foregoing results, it will be apparent that the accuracy at similar pressures of a graphite scraper contoured against the wheel is about 2-4 times greater

than that of the foil scraper system and may be more than 6 times the accuracy obtainable without a scraper or wiper.

In FIG. 13, there is shown another apparatus for carrying out electrochemical grinding of a workpiece in accordance with the present invention, the wheel 712 here being provided with a hood which performs the function of the suction nozzle 25 of FIG. 4. The hood 725 recovers the electrolyte mist and returns it to the electrolyte source. Electrolyte is delivered by the nozzle 716 whereas a suction-type pickup 725a is juxtaposed with the electrode surface for rapid removal of most of the excess electrolyte. The scraper or wiper 730, which may be identical to that of FIG. 12, is carried in a housing 760 in which a spring 761, whose force is adjustable by a screw 762, bears upon a seat 763 of the wiper 730. The latter is guided by bearings 764 within the housing so that substantially all of the spring force is effective to urge the wiper 730 against the wheel 712. A pipe 730', generally similar to the pipe 630' of FIG. 12, delivers a gas (e.g. air) under pressure and at high velocity to the interface between the wiper 630, 730 and the respective wheel 612, 712. As shown in FIG. 12, the wiper 630 is formed with an internal cavity 665 communicating with the air inlet 630' and extending substantially to the tip of the wiper 630. Thus, when the contours 630b are formed in the scraper 630, the chamber 665 opens at the contact interface to permit the air jet to sweep away excess electrolyte. I have found that this chamber 665 is best formed by a pair of graphite plates 666 and 667 formed with registering and confronting recesses and which are secured together by screws 668.

EXAMPLE V

A tungsten-carbide workpiece, containing 6% cobalt, is machined with a graphite electrode wheel whose specific resistivity, in the radial direction is about 10^{-3} Ω -cm. The workpiece has an end face of rectangular configuration with a width of 28 mm and a height of 20 mm. The electrolyte is 5% an aqueous solution containing 5% by weight potassium nitrate and the wheel has a peripheral speed of 20 m/second, a diameter of about 25 cm and a thickness of 28 mm. The machining current, applied as previously described between the wheel and the workpiece is 8 volts alternating current at 50 cycles/second. Prior to the machining operation, the periphery of the grinding wheel is contoured by a cutting tool. Thereafter, the electrode 630 or 730 is urged against the electrode and machined at 8 volts until the tip 630a bottoms in the roots of the recesses of the wheel. The power supply is disconnected from the electrode 630, 730 and is connected with the workpiece. The scraper 630, 730 is unhollowed. When cutting of the workpiece to the depth of 8 mm, a maximum error of 0.008 mm is found in the reproduction of the profiles of the electrode surface in the workpiece.

EXAMPLE VI

The process of Example V is followed except that the scraper there used is replaced by a hollow scraper 630 formed by belting together a pair of plates (FIGS. 12 and 13). The end face of the scraper is of rectangular configuration with a height of 15 mm and a width of 35 mm whereas the exposed chamber has a rectangular cross-section of 10×25 mm. The profile of the scraper is formed by electrochemical grinding for 45 minutes.

The scraper is urged against the wheel with a constant pressure of 3 kg/cm² while air is forced through the scraper at a pressure sufficient to permit the air to emerge at the interface.

At the gas pressure increases from 0 to 1 kg/cm², the accuracy increases from tolerances of 50 microns to 10–20 microns. A reproducibility of better than 10 microns is obtained with pressures between 2 and 6 kg/cm², the interfacial gap formed by the gas corresponds at these pressures to less than 0.1 mm. It is found that substantially higher accuracy can be obtained at low-material removal rates (by comparison with Example V, for instance) or that much higher machining rates (e.g. 0.8 mm/second) can be obtained with the same accuracy.

In FIG. 14, I show a modified system wherein a pair of scrapers 830a, 830b is provided, each being of the double-plate hollow type illustrated in FIGS. 12 and 13 and being supplied with a respective gas-inlet tube 830a' and 830b' for delivery of air to the contact face. Both scrapers 830a and 830b are urged by springs such as the one shown in FIG. 13 in the direction of the arrows F' and F'' against the electrode 812.

The dual-scraper arrangement of FIG. 14 is used to insure that a relatively thin film is maintained along the flanks 812f of the contours and an excess electrolyte is removed therefrom.

The plates 830a and 830b are pivoted upon respective shafts 880a and 880b and provided with arms 881a and 881b biased by springs 882a and 882b in opposite senses so that the plate 830a is urged in the counter-clockwise sense whereas the plate 830b is urged in the clockwise sense to bring the edges 830e closer to the flanks 812f of the wheel grooves.

Thus, in spite of possible inaccuracies in reproducing the contours of the wheel in the scraper, the canting of the relatively thick scrapers brings the diagonally opposite edges of the contours thereof closer to the opposite flanks of the grooves of the wheel and insures a minimum electrolyte film thickness between the scraper and a machining surface at all points along the machining face.

EXAMPLE VII

A scraper for use in Examples IV, V and VI is prepared by mixing graphite and sulfur in a weight ratio of 1:2 to 1:4, melting the mixture at a temperature between 180°C and 160°C, and thereafter casting the melt in a mold bent around the contoured face of the electrochemical grinding wheel. Upon hardening, the plate was found to have a contour complementary to that of the wheel.

I claim:

1. An electrochemical grinding apparatus, comprising:

a tool electrode with a rotatable machining surface;
means for positioning a workpiece in proximity with said machining surface, said workpiece being thereby constituted as a counterelectrode;
means for supplying electrolyte to said machining surface;

means for applying an electrochemically grinding electric current between said electrodes to electrochemically erode the workpiece at the region in which said tool electrode and said workpiece are in proximity; and

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a system for modifying the electrolyte on said machining surface prior to the entrainment thereof into the region of said workpiece to increase the accuracy of the electrochemical grinding of said workpiece, said system including a nozzle arrangement trained toward said machining surface including a nozzle arrangement trained toward said machining surface for directing a high-velocity gas jet thereagainst to strip excess electrolyte from said surface, said nozzle arrangement being located between said means for supplying electrolyte and said region and ahead of the latter in the direction of rotation of said machining surface.

2. The apparatus defined in claim 1 wherein said nozzle arrangement directs a generally flat gas jet generally tangentially against said surface.

3. An apparatus for the electrolytic treatment of metallic elements comprising at least one electrode movable with respect to the element to be treated and disposed adjacent the element to be treated, a current generator having first and second terminals respectively connected to the movable electrode and to the element to be treated, supply means for supplying an electrolyte of a composition appropriate for the treatment envisaged to the space located between the element to be treated and the movable electrode, and deflector means for acting on the flow of electrolyte between the supply means and the space located between the element to be treated and the movable electrode so

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as to cause a decrease in the thickness of the layer of electrolyte deposited on the movable electrode by the supply means such that the layer of electrolyte has the character of a thin film and preserves this thin film character as far as the space located between the element to be treated and the movable electrode, said deflector means comprising at least one nozzle for delivering a gaseous jet at high speed, said nozzle being oriented such that the gaseous jet makes contact with the movable electrode, the point of contact between the gaseous jet and the movable electrode being located between the supply means and the element to be treated.

4. The apparatus defined in claim 3 wherein the angle between the gaseous jet and an extension of the vector representing the tangential velocity of the movable electrode in the area of said pressure element is less than 90° so that a wedge of electrolyte is formed between the gaseous jet and the movable electrode.

5. The apparatus defined in claim 3 wherein said nozzle is oriented so that said gaseous jet is tangent to the movable electrode, the point of tangency then being said point of contact.

6. The apparatus defined in claim 3 wherein said nozzle is oriented so that said gaseous jet strikes the movable electrode, the point of striking then being said point of contact.

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